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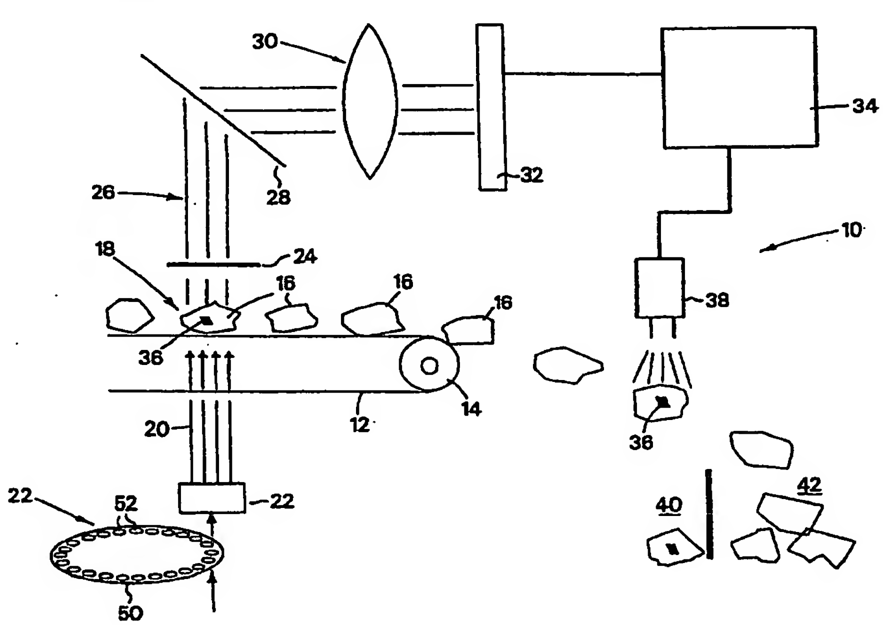
(54) Detecting diamonds in ore by neutron transmission

(57) Kimberlite particles 16 to be examined for the presence of diamonds 36 are irradiated with a beam 20 of fast neutrons at a resonant energy level for diamond. For each particle an image is derived which is representative of transmission of the beam by the particle by using a scintillator screen 24 and a CCD camera 32. The particles are then classified according to whether or not the derived image is indicative of the presence of diamond in the particle.

The method may be enhanced by irradiating the particles with neutron beams at resonant and non-resonant energy levels and forming a resultant image by subtracting one image from the other.

Fig 2



At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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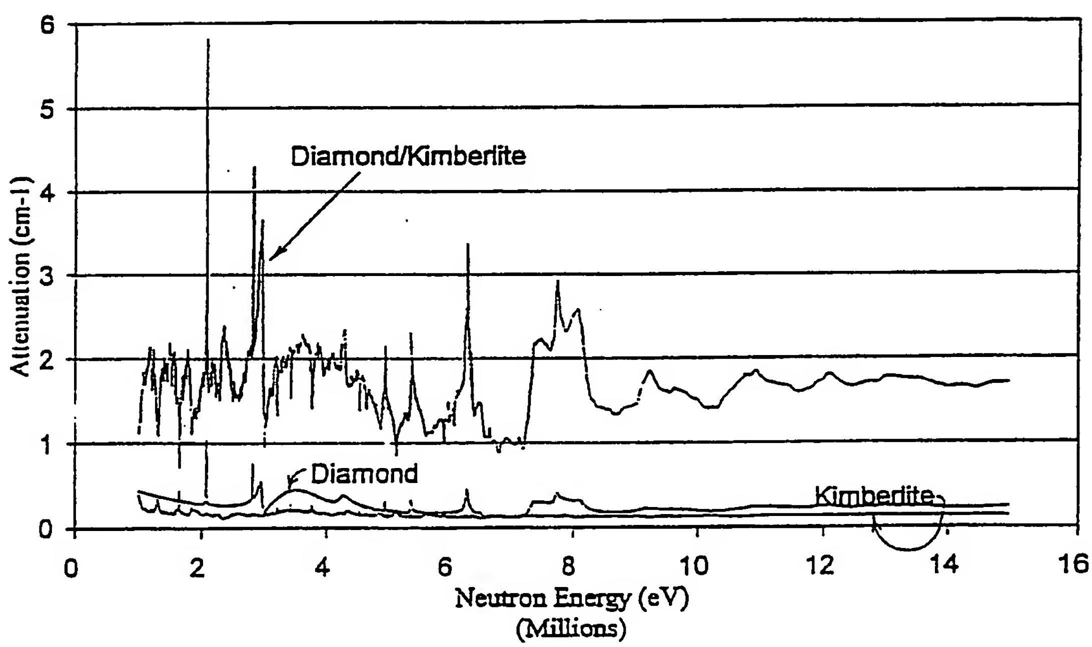
FIG 1

Neutron Attenuation Coefficient

Diamond, Kimberlite



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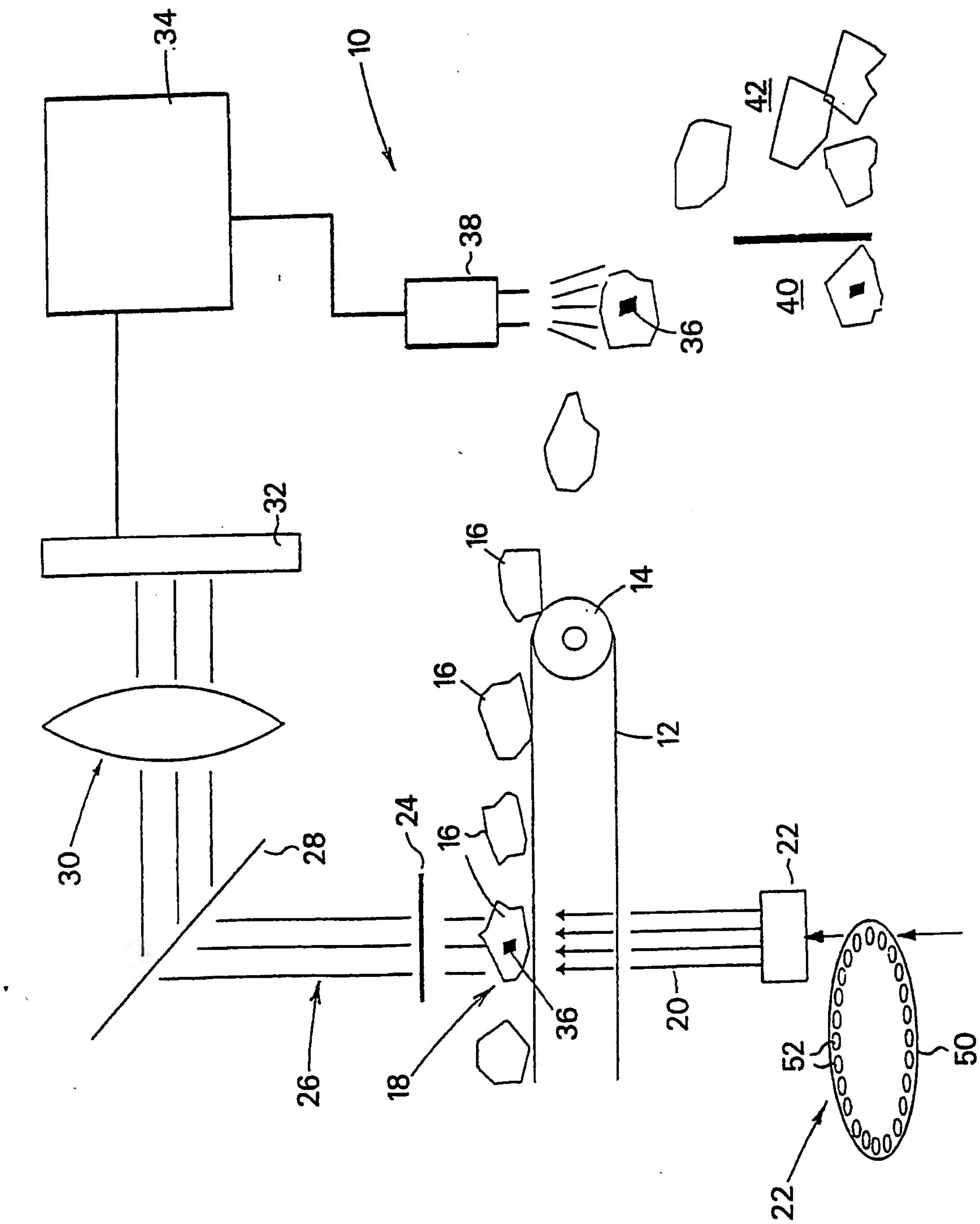

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FIG. 2

BACKGROUND TO THE INVENTION

THIS invention relates to a method and apparatus for the classification and sorting of particulate matter.

The invention has particular application to the detection of diamonds within host kimberlite particles. In practice in diamond recovery operations, it would be highly desirable to detect kimberlite particles that are host to internal diamond inclusions since it would then be possible to reject those kimberlite particles which are barren and to continue with processing of only those particles known to include diamonds. With barren particles rejected at an early stage, the load on, and capacity required of, the downstream processing equipment would be vastly reduced.

It is accordingly considered desirable to be able to form an image of the internal composition of a particle such as a kimberlite particle. One traditional imaging system uses the transmission of X-rays through the particle to form a shadowgraph of the particle. In this case, those inclusions in the particle, such as diamonds, absorb X-radiation to a greater extent than other minerals in the particle, so the diamonds appear as shadows in the image projected by the transmitted X-rays. In an alternative proposal, a computed tomography (CT or CAT) scanning system is used to form an image of the particle. In this case, a fan-shaped planar beam of X-radiation is transmitted through the particle and a detector array picks up the transmitted radiation. The X-ray source and particle are rotated relative to one another to obtain scanned views from all directions. The transmission in each picture element or pixel is determined and the totality of the data is analysed by computer to ascertain whether a certain inclusion is present in the particle.

One of the problems associated with the use of X-radiation in shadowgraph or CT scanning systems in the analysis of kimberlite particles is the fact that the X-ray attenuation coefficient for the host rock is similar to that of diamond, giving a low contrast in the resultant image between diamond and rock. A further problem is that kimberlites are known to have an inhomogeneous composition with the possibility of other mineral inclusions of similar size and X-ray attenuation characteristics as diamond. Yet another problem is the fact that X-radiation is heavily attenuated by kimberlites. The size of particles which can be analysed is therefore limited if X-ray energy and power consumption levels are to be kept within reasonable limits.

SUMMARY OF THE INVENTION

According to the present invention there is provided a method of classifying particles according to the presence or absence in the particles of a particular substance, the method comprising the steps of irradiating each particle with a beam of fast neutrons at a resonant energy level for the particular substance, deriving for each particle an image which is representative of transmission of the beam by the particle, and classifying the particle according to whether or not the derived image is indicative of the presence in the particle of the particular substance.

In this specification, the term "fast neutrons" refers to neutrons having a kinetic energy of the order of mega-electron volts. The fast neutrons preferably have a well-defined energy level. Such neutrons are in this specification referred to as being monoenergetic. It is nevertheless recognised that a perfectly monoenergetic neutron beam has not yet been achieved in practice. The neutron beam may, for instance, be produced by a beam source in which a solid target of a light element, such as beryllium, lithium or carbon is bombarded by deuterons accelerated by a particle accelerator. As an alternative, the source could be a sealed tube type source in which tritium is bombarded by deuterons.

The particles may be kimberlite particles and the particular substance may be diamond, in which case neutron beam irradiation takes place at an energy level corresponding to resonant scattering for carbon-12.

In a preferred version of the invention, each particle is irradiated by neutron beams at a first energy level corresponding to resonant scattering for the substance and also at a second, non-resonant energy level, respective first and second images representative of beam transmission are derived for the two energy levels, and a third image is derived from the first and second images, typically by subtraction, the third image also being representative of beam transmission and on the basis of which classification takes place.

In a case where kimberlite particles are classified according to whether or not they contain diamonds, the first energy level corresponds to resonant scattering for carbon-12 and the second energy level is a non-resonant energy level for carbon-12.

The particles may be irradiated in a CAT-scanning technique. As summarised above, this may be done either at a single neutron energy level, being a resonant level, or at different energy levels of which one is a resonant level.

The method may include the step of sorting the particles into fractions in accordance with their classifications.

The invention also provides an apparatus for classifying particles according to the presence or absence of a particular substance, the apparatus comprising means for irradiating the particles with a beam of fast neutrons at an energy level corresponding to resonant scattering for the particular substance, means for deriving, for each particle, an image

which is representative of attenuation of the beam by the particle, and means for classifying the particle according to whether or not the derived image is indicative of the presence in the particle of the particular substance.

The apparatus may be arranged to irradiate the particles at distinct energy levels, one being a resonant energy level and the other a non-resonant energy level.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described in more detail, by way of example only, with reference to the accompanying drawings in which:

Figure 1 shows a graph illustrating neutron attenuation for diamond and kimberlite; and

Figure 2 diagrammatically illustrates an apparatus of the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

In the description which follows, specific reference is made to the detection of carbon-containing material in rock samples and in particular the detection of diamonds in kimberlite.

When incorporated in a kimberlite matrix a diamond will appear as a highly absorbent "hot spot" under irradiation by fast neutrons having an energy level in the carbon-12 scattering cross-section which is at a resonant level for carbon-12.

In the graph in Figure 1 the line labelled "Diamond" represents neutron attenuation by diamond for various neutron energy values and the line labelled "Kimberlite" the attenuation of neutrons by kimberlite for the same range of neutron energy values. The line labelled "Diamond/Kimberlite" represents the ratio of diamond attenuation to kimberlite attenuation. Resonant scattering energy values, i.e. sharp absorption peaks, for diamond occur at neutron energy levels of, for example, 2,1 MeV, 2,9 MeV and 7,8 MeV. The most suitable energy level for selective absorption of neutrons by diamond depends on the ratio Diamond/Kimberlite. An energy level of 7,8 MeV is generally preferred.

Figure 2 illustrates an apparatus 10 for sorting kimberlite ore particles according to whether or not they contain diamonds. The apparatus 10 includes an endless belt 12 passing over a head roller 14. The belt 12 conveys kimberlite ore particles 16 through an irradiation zone 18. A collimated beam 20 of fast neutrons is produced by a source 22 and passes through the zone 18. As explained previously, the beam 20 is monoenergetic.

In the source 22, a thin, solid target of a light element such as beryllium, lithium or carbon is bombarded with a deuteron beam accelerated, to an energy in the range 1MeV to 4 MeV to produce a scattered neutron

beam at the desired energy level.

In a preferred version of the invention, the deuterons are accelerated by an RFQ accelerator to an energy level in the range 1 MeV to 4 MeV, preferably about 1,5 MeV. Depending on the material of which the target is made, and depending also on the angle between the incident deuteron beam and the scattered neutron beam, the neutron beam which is produced may have any one of a number of different energy levels. By selection of the angle between the incident deuteron beam and the scattered neutron beam, it is possible to optimise the contrast between a diamond inclusion and the host kimberlite. In the most desirable situation, the selection of the target material and of the angle between the incident deuteron and scattered neutron beams is such that there is a resonant peak at the chosen neutron beam energy level of 7,8 MeV.

In practice, the spread of energy, or energy band, at each energy level produced by bombardment of the thin target with a deuteron beam is proportional to the thickness of the target material. Thus the thinner the target material, the better defined the energy of the neutron beam, i.e. the narrower the energy band of the neutron beam. With a view to maximising the neutron flux or intensity, it is proposed to use the thickest possible target which nevertheless gives adequate definition of the neutron beam energy level.

As an alternative to the use of a thin solid target as exemplified above it would also be possible to use a sealed tritium tube type fast neutron beam source, with an accelerated deuteron beam, to produce the

required neutron beam. As yet another, less preferred alternative, the source could be one in which a deuterium gas target is bombarded by deuterons to produce a neutron beam at the required resonant energy level.

The fast neutrons are transmitted through each ore particle 16 as it passes through the irradiation zone 18 and are detected by a two-dimensional detector array in the form of a position sensitive scintillator screen 24. The light output 26 from the scintillator screen 24 is reflected by a mirror 28 and is focused by a lens 30. The focused light is viewed by a CCD (charge coupled device) camera 32 which outputs a representative electrical signal to an electronic processing unit 34. The unit 34 processes the data which it receives from the CCD camera into a two-dimensional image representative of density and composition variations, or conversely neutron beam attenuation, in the particle 16.

In another embodiment of the invention, the fast neutron beam is detected by a fibre optic scintillator coupled to the CCD camera via a standard fibre optic taper (not illustrated).

At the selected neutron energy level of 7,8 MeV, there is good contrast between a diamond 36 and the host kimberlite particle 16. An image digitising procedure carried out by the processor 34 yields an image indicating low pixel intensity at all places other than the location of the diamond 36, where a bright spot appears.

An algorithm performed by the unit 34 recognises any location exceeding a certain brightness, and accordingly the presence of a diamond, and

sends an activating signal to an ejector unit 38 located downstream of the conveyor belt 12.

After passage through the zone 18, the particles 16 are projected in free flight from the belt 12. After the appropriate time delay, the ejector unit 38 issues a short duration fluid blast at the particle trajectory. This blast deflects the diamond-containing kimberlite particles 16 out of the normal free flight trajectory and into a diamond-rich bin 40. Non-selected particles continue undeflected into a tailings bin 42.

In the embodiments described above, neutron beam irradiation of the particles takes place at a single, resonant energy level only. In a more sophisticated system, the particles are irradiated at two distinct energy levels, one being a resonant energy level and the other being a non-resonant energy level. For instance, the first neutron energy level could be 7,8 MeV as before, and the second energy level 7,0 MeV.

A digital image representative of the transmission of the neutron beam by the particle 16 is derived by the unit 34 for each neutron beam energy level. Thereafter, the digital values of the two images, stored as matrices by the unit 34, are subtracted arithmetically one from the other to form a third digital image. In the third image, which is also representative of neutron beam transmission by the particle, the effect of non-diamond components in the kimberlite particle cancel out, and any diamond inclusion gives rise to a heightened contrast and is detected by the unit 34 as a location with a brightness exceeding a threshold value. As before the unit 34 initiates the sorting procedure by the ejector 38.

The invention contemplates a particularly simple system for modulating the energy level of the neutron beam between the resonant and non-resonant values. Figure 2 diagrammatically illustrates a disc 50 formed with regularly spaced openings 52 in its periphery. Filters in the form of thin plastic foils span across alternate openings 52, while the remaining openings 52 are left open. Prior to entering the deuterium gas cell, the deuteron beam produced by the particle accelerator (not shown) encounters the disc 50 which is rotated at a predetermined velocity. When the deuteron beam passes through an opening 52 which has a filter, it is slowed down slightly and its energy level decreases accordingly. When the deuteron beam subsequently passes through the next opening 52, where there is no filter, there is no deceleration of the beam. The arrangement is such that the neutron beam produced by the deuterium gas target is modulated rapidly between an on-resonance and an off-resonance value.

This simple technique for producing distinct energy levels is considered to be more convenient than a system in which the accelerating voltage in the particle accelerator is varied periodically to produce distinct energy levels.

As an alternative to the rotating disc system described above, it would be possible to vary the emission angle of the gas target while maintaining a constant deuteron energy level.

In the illustrated embodiment, the particles 16 are conveyed on and projected from a conveyor belt. In other embodiments, the particles could be allowed to fall vertically through the irradiation zone. In yet

other embodiments, means other than a conveyor belt could be used to convey and project the particles.

In another embodiment contemplated by the invention, the neutron source could be arranged vertically so as to produce a vertical neutron beam. In this case the particulate material is presented radially to the neutron beam, at an angle corresponding to the desired angle of incidence, and with suitable detection and ejection equipment being provided at appropriate radial positions in relation to the neutron beam.

The principles of the invention are equally applicable to a CAT-scan system in which the particles are irradiated, in "slices", by a planar neutron beam. The particle and the source are rotated relative to one another, resulting in the formation of a digitised three-dimensional image. It is believed that this type of arrangement will produce more accurate results than a system as described above, but at the cost of a much slower particle analysis process.

Also, although the invention has been described in relation to the detection of carbon-containing matter, i.e. diamond in the specific embodiments referred to above, it should be appreciated that other substances could also be detected with, of course, appropriate selection of the most suitable resonant energy level. The system of the invention could, for instance, be used in the analysis of drill core samples, in which case the sample may be analysed by causing it to pass in an axial direction through the neutron beam.

CLAIMS

1.

A method of classifying particles according to the presence or absence in the particles of a particular substance, the method comprising the steps of irradiating each particle with a beam of fast neutrons at a resonant energy level for the particular substance, deriving for each particle an image which is representative of transmission of the beam by the particle, and classifying the particle according to whether or not the derived image is indicative of the presence in the particle of the particular substance.

2.

A method according to claim 1 wherein the fast neutron beam is monoenergetic.

3.

A method according to claim 2 wherein the fast neutron beam is produced by a neutron beam source in which a solid target is bombarded by a deuteron beam accelerated by a particle accelerator.

4.

A method according to claim 3 wherein the fast neutron beam is produced by a neutron beam source in which a solid target of beryllium, lithium or carbon is bombarded by a deuteron beam accelerated by a particle accelerator.

5.

A method according to claim 3 wherein the fast neutron beam is produced by a sealed tube type source in which tritium is bombarded by a deuteron beam.

6.

A method according to any one of claims 2 to 5 wherein the fast neutron beam has an energy level corresponding to resonant scattering for carbon-12.

7.

A method according to claim 6 wherein the fast neutron beam has an energy level of 7,8 MeV.

8.

A method according to claim 7 wherein the deuteron beam is accelerated to an energy level in the range 1 MeV to 4 MeV.

9.

A method according to claim 8 wherein the deuteron beam is accelerated to an energy level of about 1,5 MeV.

10.

A method according to any one of claims 6 to 9 wherein the particles are kimberlite particles and the particular substance is diamond, the particles being classified according to whether or not they contain diamonds.

11.

A method of classifying particles according to the presence or absence in the particles of a particular substance, wherein each particle is irradiated by a fast neutron beam at a first, resonant energy level for the particular substance and also at a second, non-resonant energy level, deriving for each particle respective first and second images which are representative of beam transmission by the particle at the first and second energy levels, deriving a third, resultant image from the first and second images, and classifying the particle according to whether or not the third image is indicative of the presence in the particle of the particular substance.

12.

A method according to claim 11 the fast neutron beam is produced at the first and second energy levels by a neutron beam source in which a solid target is bombarded by a deuteron beam accelerated by a particle accelerator.

13.

A method according to claim 12 wherein the fast neutron beam is produced at the first and second energy levels by a neutron beam source in which a solid target of beryllium, lithium or carbon is bombarded by a deuteron beam accelerated by a particle accelerator.

14.

A method according to claim 13 wherein the fast neutron beam is produced at the first and second energy levels by a sealed tube type source in which tritium is bombarded by a deuteron beam.

15.

A method according to any one of claims 12 to 14 wherein the first energy level is a resonant energy level for carbon-12 and the second energy level is non-resonant for carbon-12.

16.

A method according to claim 15 wherein the first energy level is 7,8 MeV.

17.

A method according to either one of claims 15 or 16 wherein the particles are kimberlite particles and the particular substance is diamond, the particles being classified according to whether or not they contain diamonds.

18.

A method according to any one of claims 11 to 17 wherein the third image is derived by subtracting the first and second images from one another.

19.

A method according to any one of the preceding claims wherein neutron beam transmission by a particle is detected by a scintillator, the output from the scintillator is viewed by a CCD camera, and signals from the CCD camera are analysed by an electronic processing unit which classifies the particle.

20.

A method according to any one of the preceding claims comprising the steps of sorting the particles into fractions in accordance with their classifications.

21.

An apparatus for classifying particles according to the presence or absence in the particles of a particular substance, the apparatus comprising means for irradiating each particle with a beam of fast neutrons at a resonant energy level for the particular substance, means for deriving, for each particle, an image which is representative of transmission of the beam by the particle, and means for classifying the particle according to whether or not the derived image is indicative of the presence in the particle of the particular substance.

22.

An apparatus according to claim 21 wherein the irradiating means comprises means for irradiating the particle with a monoenergetic fast neutron beam.

23.

An apparatus according to claim 22 comprising a neutron beam source, in which a solid target is bombarded by a deuteron beam accelerated by a particle accelerator, for producing a fast neutron beam and for irradiating the particle with the beam.

24.

An apparatus according to claim 23 wherein the solid target is of beryllium, lithium or carbon.

25.

An apparatus according to claim 23 comprising a sealed tube type source in which tritium is bombarded by a deuteron beam.

26.

An apparatus according to any one of claims 23 to 25 comprising a neutron beam source arranged to irradiate the particle with a fast neutron beam at an energy level corresponding to resonant scattering for carbon-12.

27.

An apparatus according to claim 26 wherein the neutron beam source produces a fast neutron beam at an energy level of 7,8 MeV.

28.

An apparatus according to any one of claims 23 to 27 wherein the particle accelerator is arranged to accelerate the deuteron beam to an energy level in the range 1 MeV to 4 MeV.

29.

An apparatus according to claim 28 wherein the particle accelerator is arranged to accelerate the deuteron beam to an energy level of about 1,5 MeV.

30.

An apparatus according to any one of claims 21 to 29 and comprising means for sorting the particles into fractions in accordance with their classifications.

31.

An apparatus for classifying particles according to the presence or absence in the particles of a particular substance, the apparatus comprising means for irradiating each particle with a fast neutron beam at a first, resonant energy level for the particular substance and also at a second, non-resonant energy level, means for deriving, for each particle, respective first and second images which are representative of beam transmission by the particle at the first and second energy levels, deriving a third, resultant image from the first and second images, and classifying the particle according to whether or not the third image is indicative of the presence in the particle of the particular substance.

32.

An apparatus according to claim 31 comprising a neutron beam source, in which a solid target is bombarded by a deuteron beam accelerated by a particle accelerator, for producing a fast neutron beam at the first and second energy levels, and for irradiating the particle with the beam.

33.

An apparatus according to claim 32 wherein the solid target is of beryllium, lithium or carbon.

34.

An apparatus according to claim 32 wherein the neutron beam source is a sealed tube type source in which tritium is bombarded by a deuteron beam.

35.

An apparatus according to any one of claims 31 to 34 comprising a neutron beam source arranged to irradiate the particle with a fast neutron beam at an energy level which is resonant for carbon-12 and at a second energy level which is non-resonant for carbon-12.

36.

An apparatus according to claim 34 wherein the first energy level is 7,8 MeV.

37.

A method of classifying kimberlite particles substantially as herein described with reference to the accompanying drawings.

38.

An apparatus for classifying kimberlite particles substantially as herein described with reference to the accompanying drawings.

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Examiner's report to the [redacted]ptroller under Section 17
(The Search report)

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Relevant Technical Fields

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(ii) Int Cl (Ed.6) B07C 5/34; G01N 23/02, 23/05

Databases (see below)
(i) UK Patent Office collections of GB, EP, WO and US patent specifications.

(ii) ONLINE: WPI, EDOC

Search Examiner
MR M P GILLARD

Date of completion of Search
27 FEBRUARY 1995

Documents considered relevant following a search in respect of Claims :-
ALL

Categories of documents

X: Document indicating lack of novelty or of inventive step.

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A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

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&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages	Relevant to claim(s)
A	GB 2193312 A (UK AEA)	
A	GB 1081016 A (VEITSCHER)	

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